

# On the effect of Powder Cohesion on the location of Geldart Group A to Group C Fluidisation boundaries

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**Abstract—** This study explores the potential of enhancing the predictive capability of the Geldart chart for fluidisation behaviour in wet cohesive particles by incorporating additional flow properties beyond particle size and density. Focusing on a case study involving the flatbed drying of a highly cohesive food powder, the research emphasises the importance of achieving a near-fluidisation state to maximise the thermal energy efficiency of the drying process. Basic physical characterization was performed, and bulk cohesion were measured through shear testing. Fluidisation trials were conducted at both lab and full scales. The results provided insights into the aerodynamic behaviour of the bed, guiding the integration of wet-induced cohesiveness into the application of the Geldart chart. These findings are crucial for optimizing the design and operation of flatbed drying systems and have broader implications for other materials as well.

**Keywords:** Cohesion; Geldart chart; Fluidisation; Food

## 1. Introduction

Accurately predicting the hydrodynamic behaviour of cohesive powders during aeration is crucial in various industrial applications, including flatbed drying systems. The quality of the interaction between the air and particles at the minimum fluidisation point can ensure the highest drying rate or the shortest drying time, making it the optimal condition for drying wet particles. However, predicting this aerodynamic interaction in the sub-fluidisation and fluidisation regions has proven to be particularly challenging for wet materials [1]. There have been several attempts to devise theoretical and empirical classifications of these behavioural types. Of these, the most widely used is the empirical classification of Geldart, 1973, who divides fluidisation behaviour according to mean particle size and density difference between the solids and the fluidising gas [2,3]. It is crucial to consider the fact that the Geldart classification was developed by experimenting on dry particles for which the main cohesive force is the Van der Waals forces [1]. Therefore, attempts for reinforcing the current classification by incorporating further features of the particles beyond their size and density is sought. This study seeks to showcase how cohesion among wet particles influences a shift from Group A to Group C fluidisation boundaries, highlighting the importance of considering cohesive forces in the accurate prediction of fluidisation behaviour.

## 2. Material & Methods

### 2.1. Case study product: Cassava grits

The mechanically dewatered cassava mash was pulverised to produce cassava grits, which were then subjected to a drying process. These grits, which initially contain around 45% wet based water content, tend to form lumps easily.

### 2.2. Physical and Flow Characterisation

TM3030 Plus Benchtop Electron Microscope Hitachi and a Sympatec HELOS/RODOS laser diffraction particle size

analyser were employed to investigate the morphology and particle size distribution of the samples. A shear tester of PFT, Brookfield AMETEK was used to measure bulk flow properties.

### 2.3. Fluidisation characteristics

A series of aeration experiments were conducted at both full-scale and lab-scale. Full-scale trials involved a column with a diameter of 1m and a sample depth of 0.22m, while the lab-scale tests utilised a column with a diameter of 0.15m and a depth of 0.2m.

## 3. Results and Discussion

### 3.1. Physical properties

The morphological characterization results revealed that the cassava grits consist of aggregates of smaller entities, mainly starch granules, ranging from 10 to 20 microns in size. These are accompanied by coarser fibrous particles. The particle size distribution results indicated that the grits had particle size ranges of 141-227 $\mu$ m for D10, 456-473 $\mu$ m for D50, and 724-747 $\mu$ m for D90. The particle density, ranging from 1190 to 1230 g/cm<sup>3</sup>, showed a slight increase as the water content was removed.

### 3.1. Bulk flow properties

The shear test results indicated that the bulk density ranged from 370 to 580 g/cm<sup>3</sup>, with a decrease in density as the product dried. A significant increase of up to 80% in bulk density was observed when a consolidation load reached 4.8 kPa. This significant change in the packed structure of the particles was evident in the constructed failure envelopes, and it was also reflected in the cohesion values. The cohesion values are presented in Table 1.

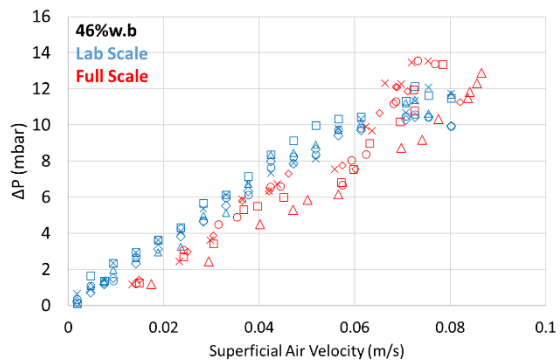
TABLE I. COHESION VALUES OBTAINED FROM SHEAR TEST

| Water Content (wet based) | Consolidation Load |         |         |
|---------------------------|--------------------|---------|---------|
|                           | 482 Pa             | 1038 Pa | 2237 Pa |
| 46 %                      | 289 Pa             | 483 Pa  | 1000 Pa |
| 31 %                      | 87 Pa              | 210 Pa  | 429 Pa  |
| 14 %                      | 40 Pa              | 73 Pa   | 149 Pa  |

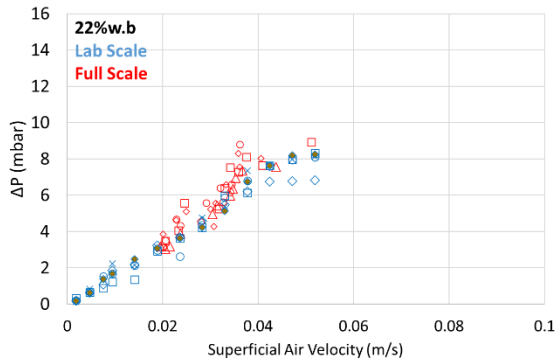
For the wet product, cohesion quantified as 289 Pa at the lowest consolidation load and increased to 1000 Pa under a consolidation load of 2237 Pa. However, after losing around one third of its water content, the cohesion values decreased significantly by a factor of 7.

### 3.2. Fluidisation Results

The sub-fluidisation behaviour of both wet and partially dry product was captured experimentally in light of the scale up effect. Figure 2 plots the experimental data for the five repeats of each trial.



a) Wet material



b) Dry material

Figure 1. Experimental data of the fluidisation tests.

The superficial air velocity through the particles could reach up to 8.5 m/s for wet materials and 5.2 m/s for dry materials. At the same time, the gauge pressure beneath the material, just before fluidisation occurred, ranged between 10 and 14 mbar. In the lab scale trials, the material showed a slightly expansion before reaching the fluidisation point. But in the full-scale trials, the bed tends to bend due to the air back pressure beneath it rather than showing expansion and as a result a sudden loss of the static state of the bed happened. Nevertheless, no significant differences were obtained between the lab scale and full-scale trials for dry state of the material. This trend can also be linked to the decreasing magnitude of interparticle forces as the material dries. It is important to consider the impact of back pressure from the air beneath the material layer, which can be mimicked by applying a consolidation load during shear testing to measure cohesion. As shown in the shear test results in Table 1, the cohesion of the wet material was significantly affected by the consolidation load, whereas the dry material showed much less impact.

### 3.3. Cohesion in Geldart Classification

A significant deviation from Geldart classifications was observed when the case study material had higher water content level. A channelling behaviour occurred when the wet material reached the fluidisation stage while a smooth aeration with bubbling was expected according to the Geldart chart shown in Figure 2. Similar behaviour has been observed for products with starchy nature [2], reported channelling and agglomeration of dry corn-starch particles (15  $\mu\text{m}$ ), falls in Geldart Group C, during the attempts to fluidisation. It seems reasonable to interpret the boundary shift in Geldart classification as if it possessed finer particles in interaction with the flowing air. The wet surface of the freshly prepared cassava grits greatly enhances interparticle forces, similar to how a finer particle size distribution can lead to increased cohesion compared to coarser particles.

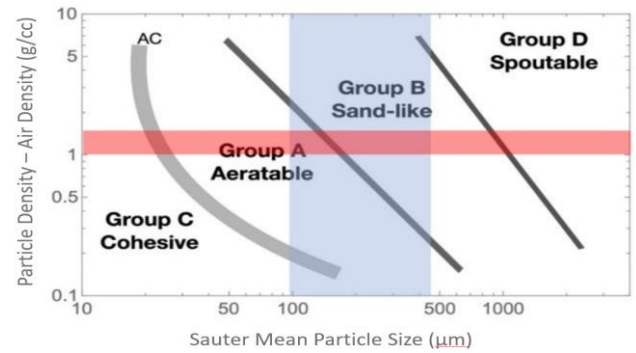


Figure 2. Geldart chart and classification; highlighting the expected region based on the physical properties of the product

Additionally, the hydrostatic pressure exerted by the stagnant air beneath the material layer served as a consolidating load, resulting in an increase in cohesion. Consequently, the particles began adhering together, forming agglomerates that ultimately blocked the existing air paths, thereby promoting the plunge lifting motion of the bed. Therefore, instead of exhibiting bubbling or slugging movement of air through the material layer, the fluidisation behaviour primarily showed channelling. However, the impact of this consolidating force on cohesion decreased as the material dried. This rationale finds support in the trend that emerged as the material became drier and gradually began to align more closely with the predictions presented in the Geldart graphs. This logical connection underscores the role of cohesion in predicting the fluidisation behaviour.

## 4. Conclusion

Despite the well-accepted utility of the Geldart classification, it should be used with an awareness of its limitations. This research showcases how incorporating the concept of cohesion can improve the prediction of fluidisation behaviour. Although cohesion, due to factors such as particle size or moisture content, is a complex concept and must be defined according to the measurement procedure, the study shows that cohesion measured through shear testing can be a promising indicator. Nonetheless, further investigation is needed to develop a systematic approach for incorporating cohesion into fluidisation predictions.

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